

WHAT IS CLAIMED IS:

5           1. A three-dimensional steering tool for use in  
drilling a borehole in an underground formation in which an  
elongated conduit extends from the surface through the  
borehole and in which the steering tool is mounted on the  
conduit near a drill bit for drilling the borehole, the  
10          steering tool comprising an integrated telemetry section,  
rotary section and flex section aligned axially along the  
steering tool for separately controlling inclination and  
azimuth angles at the drill bit; in which the flex section  
includes an elongated drive shaft coupled to the drill bit and  
15          adapted to be rotatably driven for rotating the drill bit, the  
drive shaft being bendable laterally to define a deflection  
angle thereof, and a deflection actuator coupled to the drive  
shaft, the deflection actuator comprising a deflection housing  
surrounding the drive shaft and having a longitudinal axis and  
20          an elongated deflection piston movable in the deflection  
housing for applying a lateral bending force to the drive  
shaft for making changes in the deflection angle of the drive  
shaft and which is transmitted to the drill bit as an  
inclination angle steering adjustment; in which the rotary  
25          section is coupled to the actuator and includes a rotator  
actuator for transmitting a rotational force to the deflection  
actuator to rotate the deflection piston to thereby change the  
rotational angle at which the lateral bending force is applied  
to the drive shaft which is transmitted to the drill bit as an  
30          azimuth angle steering adjustment; and in which the telemetry  
section measures the inclination angle and the azimuth angle  
during drilling and compares them with desired inclination and  
azimuth angle information to produce inclination control  
signals for operating the deflection actuator to make steering  
35          adjustments in the inclination angle and for separately

producing azimuth control signals for operating the rotator actuator for making steering adjustments in the azimuth angle.

5                     2. Apparatus according to claim 1 in which the conduit is an elongated rotary drill string.

10                  3. Apparatus according to claim 1 in which the deflection actuator comprises an elongated deflection housing surrounding the drive shaft, and an elongated hydraulically operated piston in the deflection housing for applying the bending force distributed lengthwise along the drive shaft for flexing the drive shaft laterally to produce said deflection angle thereof to thereby change the inclination angle at the drill bit.

20                  4. Apparatus according to claim 3 in which the rotator actuator is coupled to the deflection housing and includes a rotator piston movable in proportion to a desired change in the azimuth angle and a helical gear arrangement on the deflection housing coupled to the rotator piston and rotatable in response to piston travel to rotate the deflection housing to change the azimuth angle at the drill bit.

25                  5. Apparatus according to claim 1 in which the hydraulically powered bending force is applied to the deflection piston by drilling mud taken from an annulus between the conduit and the borehole.

30                  6. Apparatus according to claim 1 in which the deflection actuator applies the bending force to the drive shaft while the rotary actuator applies the rotational force to the deflection actuator for making simultaneous adjustments 35 in the inclination angles and the azimuth angles.

5           7. Apparatus according to claim 1 in which the feedback loop comprises a closed loop controller including a comparator for receiving the measured and desired inclination angle and azimuth angle command signals for producing inclination and azimuth error signals for making the steering adjustments.

10          8. Apparatus according to claim 1 in which the telemetry section comprises an onboard mud pulse telemetry section for receiving the desired inclination and azimuth angle input signals and utilizing mud pulse controls for operating the deflection actuator and the rotator actuator from drilling mud taken from an annulus between the conduit 15 and the borehole.

20          9. The apparatus according to claim 8 in which the mud pulse telemetry section provides open loop control to the deflection actuator and the rotator actuator, and in which electrical controls provide closed loop control to the 25 actuators.

30          10. Apparatus according to claim 1 in which the deflection actuator includes axially spaced-apart end bearings for mounting the drive shaft along a longitudinal axis of the steering tool, and a deflection piston for applying the lateral bending force to the drive shaft between the end bearings to bend the drive shaft while the end bearings constrain the drive shaft on opposite sides of the deflection piston.

35          11. Apparatus according to claim 1 in which the deflection piston contained in the deflection housing is positioned on one side of the drive shaft and the drive shaft has a longitudinal axis aligned with a longitudinal axis of

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the deflection housing, and the lateral bending force is  
applied by the piston as a unitary force which physically  
5       bends the drive shaft to deflect its longitudinal axis away  
from the axis of the deflection housing.

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